

**English translation of JP-A-2002-151267**

(54) [Title of the Invention]

Light-emitting device

(57) [Abstract]

[Problem]

To provide a single layer device in which an organic compound layer is arranged between a pair of electrodes provided on a substrate, which is a novel light emitting device capable of attaining favorable carrier balance, being driven at a low voltage and having high luminance and high light-emission efficiency, and also having high temperature preservation durability.

[Means for Resolution]

A light-emitting device in which an organic compound layer is formed between a pair of electrodes provided on a substrate characterized in that the organic compound layer has an electron mobility of  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more at an electric field intensity in a range from 400 to 1,000  $(\text{V/cm})^{1/2}$ , and the organic compound layer contains a light-emitting compound.

[Claims]

[Claim 1]

A light-emitting device in which an organic compound layer is formed between a pair of electrodes provided on a substrate characterized in that said organic compound layer has an electron mobility of  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more at an electric field intensity in a range from 400 to 1,000  $(\text{V/cm})^{1/2}$ , and said organic compound layer contains a light-emitting compound.

[Claim 2]

The light-emitting device according to claim 1, characterized in that the lowest excited triplet energy levels of compounds other than the light-emitting compound used in the organic compound layer are greater than the lowest excited triplet energy level of the light-emitting compound contained in said organic compound layer.

[Claim 3]

The light-emitting device according to claim 1 or 2, characterized in that the lowest excited triplet energy levels of compounds other than a phosphorescent compound used in the organic compound layer are 40 kcal/mol or more and 90 kcal/mol or less.

[Claim 4]

The light-emitting device according to any one of claims 1 to 3, characterized in that an ionization potential of the organic compound layer or a hole injecting compound, a hole transporting compound, a hole injecting and transporting compound or a host compound used in the organic compound layer is 4.7 eV or greater.

[Claim 5]

The light-emitting device according to any one of claims 1 to 4, characterized in that at least one compound out of the compounds used in the organic compound layer contains an aromatic hetero ring having one or more hetero atoms.

[Claim 6]

The light-emitting device according to any one of claims 1 to 5, characterized in that the organic compound layer contains at least one of arylamine and derivatives thereof.

[Claim 7]

The light-emitting device according to any one of claims 1 to 6, characterized in that at least one compound out of the compounds used in the organic compound layer is a conjugated polymer.

[Claim 8]

The light-emitting device according to any one of claims 1 to 7, characterized in that at least one compound out of the compounds used in the organic compound layer is a polymer having a partial structure represented by the following general formula (I):

[Chemical formula 11]

-Ar-Het-Ar-    General formula (I)  
 (wherein Ar represents a hydrocarbon aromatic ring, Het represents an aromatic hetero ring having one or more nitrogen atoms).

[Claim 9]

The light-emitting device according to any one of claims 1 to 8, characterized in that the light-emitting compound used in the organic compound layer is at least one of ortho-metalated metal complexes and porphyrin metal complexes which are phosphorescent compounds.

## [Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a polymer having a

high carrier injecting property and a carrier transporting property, and materials for an organic electroluminescent device capable of emitting light by converting electric energy to light (hereinafter referred to as a light-emitting device), and a light-emitting device, and also relates to a light-emitting device suitably used for fields of display devices, displays, back lights, electrophotography, illumination light sources, recording light sources, read light sources, signs, advertising displays, interiors and the like.

[0002]

[Prior Art]

Research and development concerning various display devices is active today, and in particular, light emitting devices have attracted attention as promising display devices because they can emit light with high luminance at a low voltage. For example, light-emitting devices in which organic thin films are laminated by vapor-deposition of an organic compound (laminated devices) have been known (Applied Physics Letters, vol. 51, P.913 (1987)). Various methods of improving light emitting efficiency by laminate devices have been reported, however, manufacture of devices by vapor deposition of a low molecular organic compound has complicated fabrication steps and involves problems in workability, productivity from a view point of increasing in the area. In manufacture of laminated devices using polymeric materials, the coating step in the fabrication process is complicated and moreover, it is necessary to control the solubility of the material of each layer or to cure the layer, resulting in too many problems to be put into practical use.

[0003]

For minimizing the fabrication process for the light-emitting device, the configuration of a single layer device in which an organic compound layer of a single layer structure is arranged between a pair of electrodes provided on a substrate is more preferred than the configuration of laminated devices. As a material for the single layer light-emitting device which is advantageous in productivity,  $\pi$  conjugated polymers represented, for example, by polyparaphenylene vinylene (PPV) are known, however, they involve too many problems, for example, in color tone, emission intensity, emission efficiency and durability to be put into practical use. Likewise, devices in which a low

molecular fluorescent compound is dispersed in poly(N-vinyl carbazole) are disclosed (JP-A-4-212286). In this method, since the kind of the fluorescent compound can be optionally changed, the color tone and light emission intensity can be controlled relatively easily. However, the method involves significant practical problems that driving voltage is high due to low carrier mobility, and favorable carrier balance cannot be attained because the mobility of holes and the mobility of electrons are different. Moreover, the method also involves a problem in the durability, e.g., the luminance tends to be lowered when the devices are driven after long period of time or driven continuously.

[0004]

On the other hand, as means for improving quantum efficiency of light-emitting devices, green light-emitting devices prepared using light emission from an iridium complex, reported in Applied Physics Letters, (Vol. 75, paragraph 4, (1999)) are known. The devices attained external quantum efficiency of 8% that exceeds the external quantum efficiency of 5% which had been said to be the limit of devices. However, the device has problems not only in the complicated fabrication process due to its multi-layered structure but also in the durability. In addition, even devices having the iridium complex dispersed in the poly(N-vinyl carbazole) (PVK) described above also have problems that the driving voltage is high because carrier mobility of the PVK is low, and favorable carrier balance cannot be attained because the mobility of holes and the mobility of electrons are different.

[0005]

[Problems that the Invention is to Solve]

An object of the present invention is to provide a single layer device in which an organic compound layer is arranged between a pair of electrodes provided on a substrate, which is a novel light-emitting device capable of attaining favorable carrier balance, being driven at a low voltage and having high luminance and high light-emission efficiency, and also having high temperature preservation durability.

[0006]

[Means for Solving the Problems]

In order to achieve the object, the present inventors have made intensive studies, as a result, they attained the object by a single layer device not by conventional laminated devices which involve a problem in their manufacturing

adaptability. The object was attained by the means of the present invention described below.

(1) A light-emitting device in which an organic compound layer is formed between a pair of electrodes provided on a substrate, characterized in that the organic compound layer has an electron mobility of  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more at an electric field intensity in a range from 400 to 1,000  $(\text{V/cm})^{1/2}$ , and the organic compound layer contains a light-emitting compound.

(2) The light-emitting device as described in (1), characterized in that the lowest excited triplet energy levels of compounds other than the light-emitting compound used in the organic compound layer are greater than the lowest excited triplet energy level of the light-emitting compound contained in the organic compound layer.

(3) The light-emitting device as described in (1) or (2), characterized in that the lowest excited triplet energy levels of compounds other than a phosphorescent compound used in the organic compound layer are from 40 kcal/mol or more and 90 kcal/mol or less.

(4) The light-emitting device as described in any one of (1) to (3), characterized in that the ionization potential of the organic compound layer or a hole injecting compound, a hole transporting compound, a hole injecting and transporting compound or a host compound used in the organic compound layer is 4.7 eV or more.

(5) The light-emitting device as described in any one of (1) to (4), characterized in that at least one compound out of the compounds used in the organic compound layer contains an aromatic hetero ring having one or more hetero atoms.

(6) The light-emitting device as described in any one of (1) to (5), characterized in that the organic compound layer contains at least one of arylamine and derivatives thereof.

(7) The light-emitting device as described in any one of (1) to (6), characterized in that at least one compound out of the compounds used in the organic compound layer is a conjugated polymer.

(8) The light-emitting device as described in any one of (1) to (7), characterized in that at least one compound out of the compounds used in the organic compound layer is a polymer having a partial structure represented by the following general formula (I).

[0007]

[chemical formula 2]

-Ar-Het-Ar-

General formula (I)

[0008]

(wherein Ar represents a hydrocarbon aromatic ring, Het represents an aromatic hetero ring having one or more nitrogen atoms).

(9) The light-emitting device as described in any one of (1) to (8), characterized in that the light-emitting compound used in the organic compound layer is at least one of orthometalated metal complexes and porphyrin metal complexes which are phosphorescent compounds.

[0009]

[Mode for Carrying Out the Invention]

The present invention will be described more specifically below. It is to be noted that, in the description, ranges indicated with "to" mean ranges including the numerical values before and after "to" as the minimum and maximum values.

[0010]

The light-emitting device of the present invention has a configuration having an organic compound layer as a light-emitting layer formed between a pair of electrodes including an anode and a cathode, and may have a protecting layer in addition to the light-emitting layer, in which each of the layers may have another function. Various materials may be used respectively for the formation of each layer.

[0011]

The organic compound layer of the light-emitting device of the invention has a single layer structure for the purpose of simplifying the fabrication process, and is designed so that the balance between the hole mobility and the electron mobility in the layer is maintained favorably for improving light-emitting efficiency. Accordingly, the organic compound layer of the invention does not have a laminate structure. The organic compound layer that is used contains several materials selected from electron injecting compounds, electron transporting compounds, compounds having both electron injecting and transporting properties (electron injecting and transporting compounds), hole-injecting compounds, hole transporting compounds, compounds having hole injecting and hole transporting properties (hole injecting and transporting compounds), compounds having both electron injecting and transporting properties and hole injecting and

transporting properties respectively (electron injecting and transporting compounds also serving as hole injecting and transporting compounds), light-emitting compounds, host compounds, electron donating dopants, and electron receiving dopants, etc. while being combined so as to maintain carrier balance favorably.

[0012]

The organic compound layer of the invention may be constituted only with low molecular compounds, or may be constituted with only high molecular weight compounds. However, it is preferred that the organic compound layer be constituted with a mixture of high molecular compounds and low molecular compounds in view of simplicity of the fabrication process and durability of the devices.

[0013]

The compounds other than the light-emitting compound in the organic compound layer of the invention are compounds not emitting light, when electric fields are applied, among the compounds contained in the layer. Likewise, the compounds other than the phosphorescent compound in the organic compound layer of the invention are compounds not emitting phosphorescence, when electric fields are applied, among compounds contained in the layer.

[0014]

The light-emitting compound of the invention is a compound which emits fluorescence or phosphorescence (a fluorescent compound or phosphorescent compound), and the phosphorescent compound is preferably used from a view point of light-emitting efficiency.

[0015]

The host compound of the invention is a compound having a function of allowing a fluorescent compound or a phosphorescent compound to emit light by energy transfer from the excited state to the fluorescent compound or the phosphorescent compound as the light emitting compound described above (a fluorescent host compound or a phosphorescent host compound).

[0016]

The compounds including, for example, the electron injecting compound, the electron transporting compound, the electron injecting and transporting compound, the hole injecting compound, the hole transporting compound, the hole injecting and transporting compound, the electron injecting

and transporting compound also serving as a hole injecting and transporting compound, a light emitting compound, the host compound, the electron donating dopant, and the electron accepting dopant, contained in the organic compound layer to be used in the invention may have properties or parts having several functions. Alternatively, respective functions may be provided to different components.

[0017]

The compound having the partial structure represented by the general formula (I) of the invention may comprise either a low molecular weight compound or a high molecular weight compound. When the compound is a high molecular compound, it may be a homopolymer, or may be a copolymer with other monomers. The copolymer may be a random copolymer, an alternate copolymer, a block copolymer, or a graft copolymer. In addition, the compound may be a starburst homopolymer or copolymer.

[0018]

In the organic compound layer of the light-emitting device of the invention, it is preferred to use an electron transporting compound and/or a hole transporting compound as a matrix for lowering driving voltage and to use other compounds dispersed in the matrix. In this case, the electron transporting compound and the hole transporting compound to be used as a matrix may comprise either a low molecular weight component or a high molecular weight compound. Alternatively, two or more matrices may be used as a mixture.

[0019]

The host compound may be a compound having both electron injecting and electron transporting properties (an electron injecting and transporting compound). The ratio of contribution of the electron injecting property to that of the electron transporting property attributable to the electron injecting and transporting compound may be different depending on the compounds. In addition, the host compound may be a compound having both hole injecting and hole transporting properties (a hole injecting and transporting compound). The ratio of contribution of the hole injecting property to that of the hole transporting property attributable to the hole injecting and transporting compound may be different depending on the compounds. In addition, the host compound may be a compound having electron injecting and electron transporting properties, as well as hole injecting

and holt transporting properties respectively (an electron injecting and transporting compound also serving as a hole injecting and transporting compound). The ratio of contribution of the electron injecting and transporting properties to that of the hole injecting and transporting properties attributable to the electron injecting and transporting compound also serving as a hole injecting and transporting compound may be different depending on the compounds.

[0020]

The electron transporting compound and the hole transporting compound may be used while being dispersed in a polymer imparting no significant effects on carrier transfer, such as polymethyl methacrylate or polycarbonate. Although a single layer device comprising a compound having a hole transporting property and a function as a host compound, such as polyvinyl carbazole, as a matrix, has been reported, the polyvinyl carbazole has an electron mobility as small as about  $1.0 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1}\text{s}^{-1}$ , and a hole mobility as small as about  $5.0 \times 10^{-6} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  at an electric field intensity in the range to use, resulting in extremely high driving voltage, and involves problems that the hole mobility and the electron mobility are imbalanced, and the light-emitting quantum efficiency is low.

[0021]

The electron mobility of the organic compound layer of the invention is preferably about  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more, more preferably  $1 \times 10^{-4} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more, and furthermore preferably,  $5 \times 10^{-3} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more from a view point of driving voltage.

[0022]

The electron mobility of the organic compound layer is defined by the electron mobility of each of the compounds per se constituting the layer such as the electron injecting compound, the electron transporting compound, the electron injecting and transporting compound, the hole injecting compound, the hole transporting compound, the hole injecting and transporting compound, and the electron injecting and transporting compound also serving as a hole injecting and transporting compound, and the electron mobility is defined also by the amount for the mixture of the compounds. As the compound having the electron mobility, hetero atom-containing organic compounds, electron transporting organic compounds,

organic compound complexes, organic metal complexes, organic metal compounds, charge transfer complexes and polymers, conjugated polymers, and conductive polymers thereof are known as major compounds, however, the compounds may be arbitrary selected and used with no particular restriction so long as they have the electron mobility described above. Among the examples described above, nitrogen-containing organic compounds, oxygen-containing organic compounds, sulfur-containing organic compounds, boron-containing organic compounds, silicon-containing organic compounds, phosphorus-containing organic compound, liquid crystal organic compounds, crystalline organic compounds, organic compound complexes, organic metal complexes, organic metal compounds, charge transfer complexes, conjugated polymers, etc. are preferred, and among them, hetero atom-containing aromatic organic compounds, charge transfer complexes of hetero atom-containing aromatic organic compounds, organic metal compounds, charge transfer complexes, liquid crystal organic compounds, crystalline organic compounds, and polymers and conjugated polymers thereof are more preferred.

[0023]

The electron mobility in the invention can be measured according to time-of-flight (hereinafter referred to as TOF) method. The TOF method is referred to the descriptions of Synthetic Metals, 111-112, p 331 (2000).

[0024]

The lowest excited triplet energy levels of the compounds other than the light-emitting compound used in the organic compound layer are preferably equal to or greater than the lowest excited triplet energy level of the light-emitting compound.

[0025]

The lowest excited triplet energy levels of the compounds other than the phosphorescent compound used in the organic compound layer are determined by the compound having the lowest excited triplet energy level which is the lowest in the layer. When a compound having the lowest excited triplet energy level which is lower than that of the light-emitting compound is contained in the layer, the device does not emit light.

[0026]

In particular, in the case where a phosphorescent compound is used as the light-emitting compound, the lowest

excited triplet energy levels of the compounds other than the phosphorescent compound to be used in the organic compound layer should be arbitrary selected depending on the color of phosphorescence, however, it is preferably, 40 kcal/mol to 90 kcal/mol, more preferably, 45 kcal/mol to 90 kcal/mol, and furthermore preferably, 50 kcal/mol to 90 kcal/mol, inclusive respectively.

[0027]

The ratio of the electron mobility to the hole mobility of the organic compound layer of the invention is preferably 0.5 to 1.5, more preferably, 0.8 to 1.2, and furthermore preferably, 0.9 to 1.1 from a view point of luminescent quantum efficiency.

[0028]

The ionization potential of the compound used in the organic compound layer of the invention is usually determined by a compound having the smallest value. The ionization potential of the compound is preferably 4.7 eV or more, more preferably, 4.8 eV or more, and furthermore preferably, 4.9 eV or more from a view point of a hole injection property. The ionization potential of the arylamine derivative to be used in the organic compound of the invention is preferably 5.0 eV or more, more preferably, 5.1 eV or more and, furthermore preferably, 5.2 eV or more also from a view point of the hole injecting property.

[0029]

In the case where the compound to be used in the organic compound layer of the invention is a high molecular compound, the average molecular weight thereof depends on the kind of substituents so it is not uniform, however, it is preferably 1,000 to 1,000,000, more preferably, 1,500 to 700,000, furthermore preferably, 2,000 to 500,000.

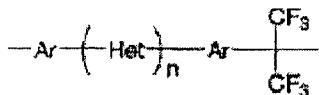
[0030]

As Ar in the general formula (I), a hydrocarbon aromatic ring having from 6 to 20 carbon atoms is preferred, and a benzene ring, a naphthalene ring, and an anthracene ring are more preferred, with a benzene ring, and a naphthalene ring being particularly preferred. The aromatic rings may have a substituent. In the general formula (I), Het is preferably an electron deficient aromatic hetero ring having one or more nitrogen atoms, and pyridine, pyrazine, pyrimidine, pyridazine, quinoline, isoquinoline, quinoxaline, phthalazine, quinazoline, dipyridine, triazolo pyrimidine,

phenanthroline, naphthyridine, imidazole, pyrazole, oxazole, oxadiazole, triazole, triazine, thienopyrazine, thiadiazole, benzimidazole, benzoxazole, benzotriazole, benzotriadine benzthiazole, and phenanthridine are more preferred, with pyridine, pyrazine, quinoline, quinoxaline, bipyridine, oxazole, oxadiazole, triazole, and triazine being furthermore preferred. They may have one or more substituents, and may form a condensed ring. As examples of the substituent, an alkyl group having up to 11 carbon atoms, an aryl group having up to 20 carbon atoms, an aralkyl group up to 20 carbon atoms, a (thio)alkoxy group having up to 11 carbon atoms, a (thio)aryloxy group having up to 20 carbon atoms, a cyano group, a fluoro group, a chloro group, and a trifluoromethyl group are preferred, and an alkyl group, an aralkyl group, an alkoxy group, a cyano group, a fluoro group, a trifluoromethyl group are more preferred, with an alkyl group, an aralkyl group, an aryl group, an alkoxy group, and a trifluoromethyl group being furthermore preferred. Among the compounds represented by the general formula (I), compounds represented by the following general formula (II) are preferably used.

[0031]

[chemical formula 3]



General formula (II)

[0032]

In the general formula (II), Ar and Het have the same meanings as those in the general formula (I), and their preferable ranges are also the same. The value n which is in the lower right of the parenthesis in the chemical formula is 1 or 2, and represents a number of repeating units.

[0033]

Specific examples of the compound having the partial structure represented by the general formula (I), and the electron injecting and transporting compound, the hole injecting and transporting compound, and the electron injecting and transporting compound also serving as a hole injecting and transporting compound used as a matrix used in the invention are shown respectively below, however, the invention is not restricted to them. In the figure, the

molecular weight (in terms of polystyrene) is a mass average molecular weight ( $M_w$ ) or a number average molecular weight ( $M_n$ ). The parenthetic part in the chemical formula expresses a repeating unit, and the compound may be an oligomeric or polymeric compound having a plurality of the units.

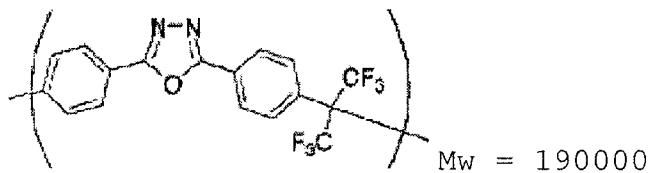
[0034]

Typical examples of a particularly effective electron injecting and transporting compound to be used in the invention are shown below.

[0035]

[chemical formula 4]

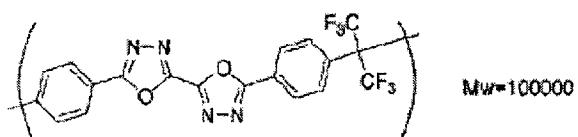
E-1



$M_w = 190000$

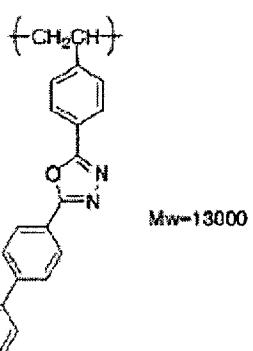
$M_w$  = mass average molecular weight (in terms of polystyrene)

E-2



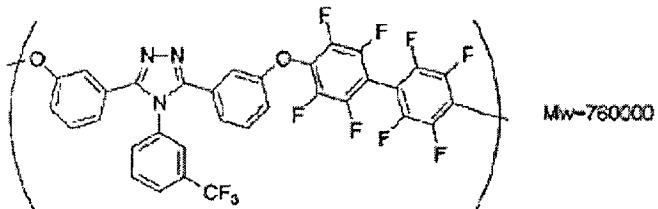
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E-3



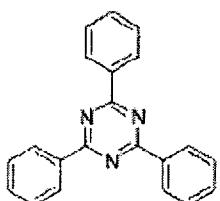
$M_w=13000$

E-4

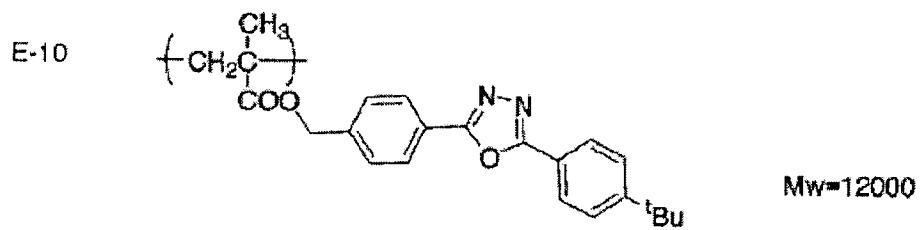
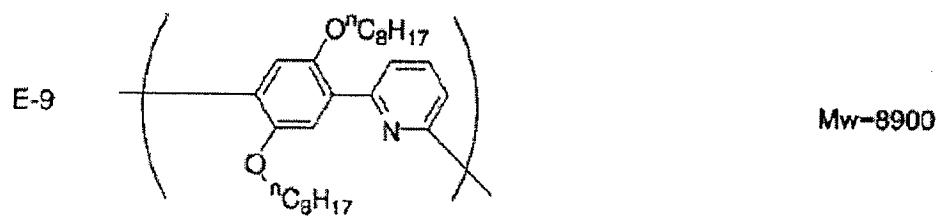
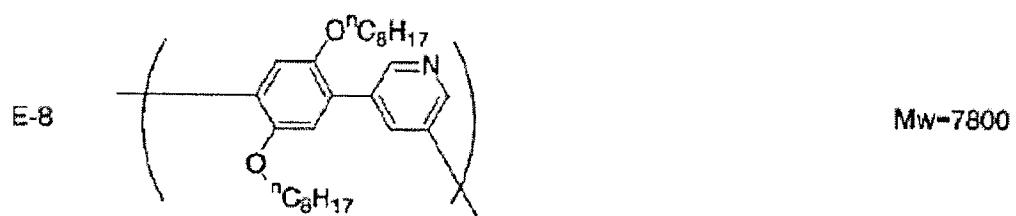
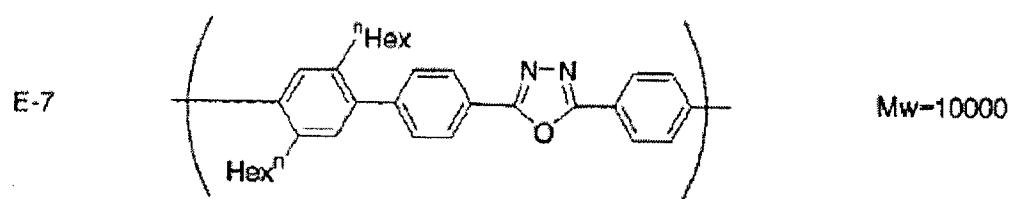
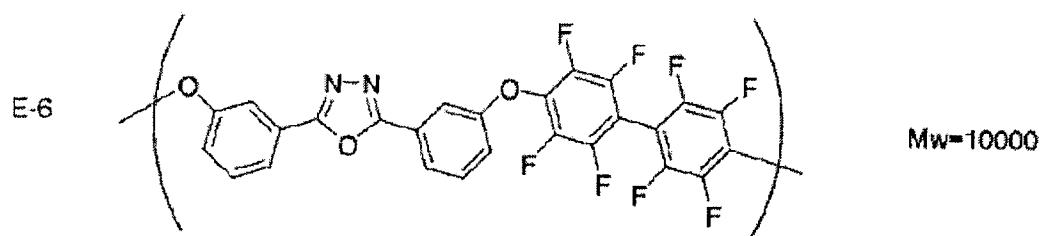


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E-5



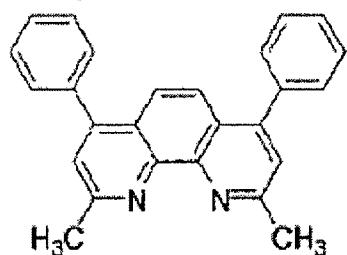
[0036]  
[chemical formula 5]



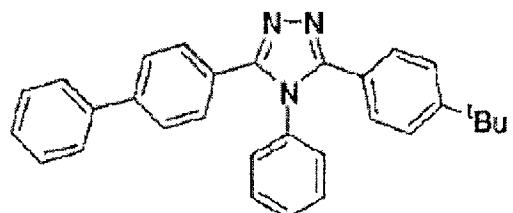
[0037]

[chemical formula 6]

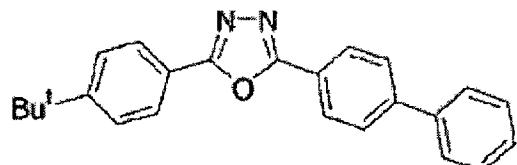
E-11



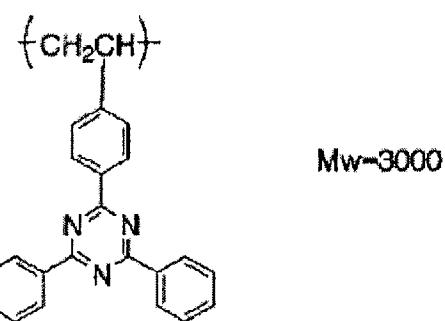
E-12



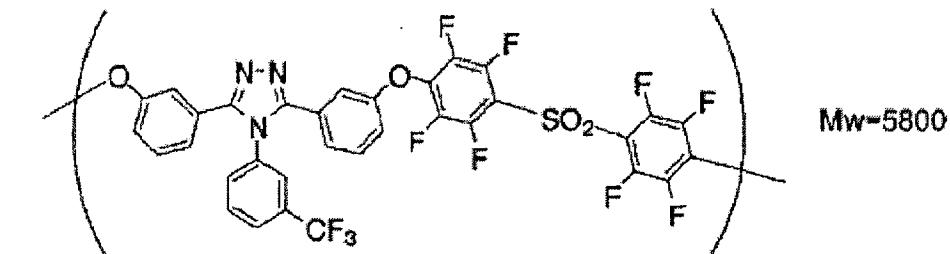
E-13



E-14

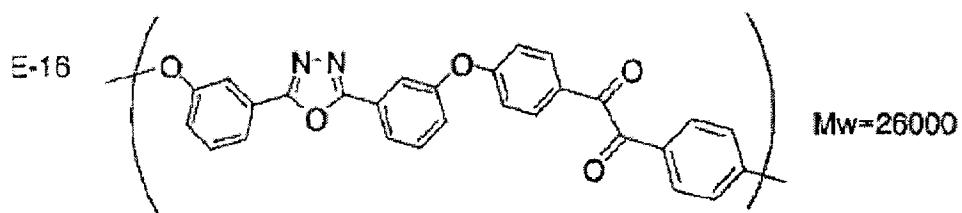


E-15

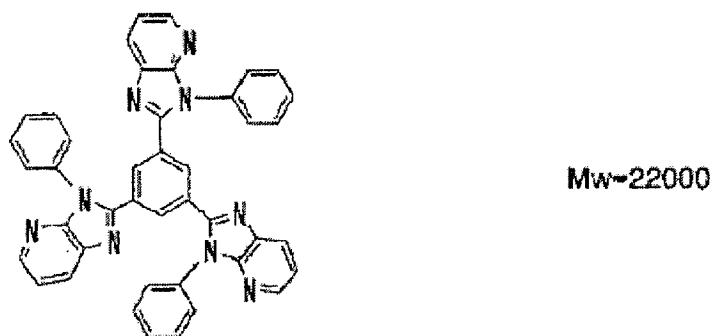


[0038]

[chemical formula 7]

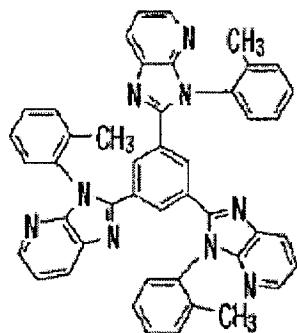


E-17



Mw=22000

E-18

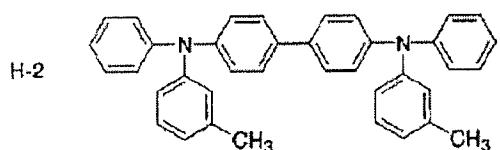
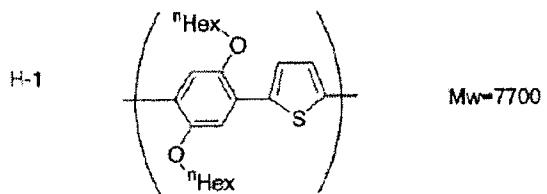


[0039]

Typical examples of a particularly effective hole injecting and transporting compound to be used in the invention are shown below.

[0040]

[chemical formula 8]

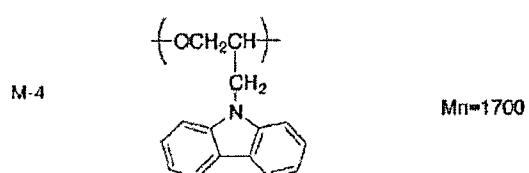
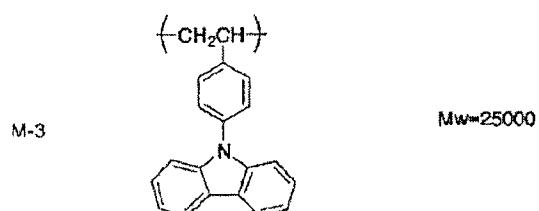
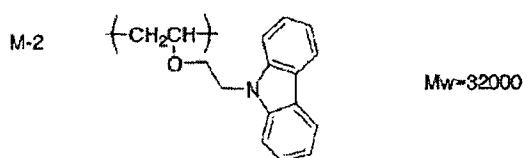
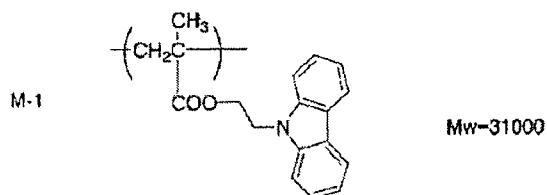


[0041]

Typical examples of a particularly effective electron injecting and transporting compound also serving as a hole injecting and transporting compound to be used in the invention are shown below.

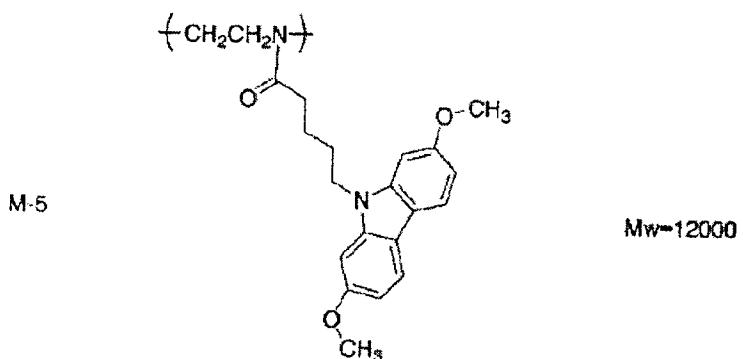
[0042]

[chemical formula 9]

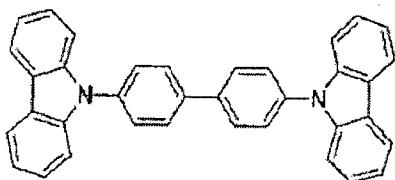


[0043]

[chemical formula 10]



M-6



[0044]

When the compound used in the light-emitting device of the invention is a polymeric compound, a solvent and a coating solvent for dissolving the compound can be freely selected depending on the structure of the polymer. In the case of a high polar compound, the compound can be dissolved in various high polar solvents such as water, methanol and other alcohols, formic acid, acetic acid, cellosolve solvents, glycol-based solvents, and dioxane, and solvents of their mixtures. On the other hand, in the case of a low polar compound, the compound can be dissolved in various low polar solvents such as tetrahydrofuran, halogen-containing hydrocarbon solvents and aromatic hydrocarbon solvents.

[0045]

The organic compound layer which is used in the invention may be provided on a thin layer of an aqueous coating such as of a PEDOT-PSS film (polyethylene dioxythiophene-polystyrene sulfonic acid-doped body). In providing the organic compound layer of the invention, both a low molecular deposition process and a coating process may be used. In the case of using a coating process, preferable coating solvents include water, methanol, ethanol, propanol, isopropanol, butanol, formic acid, acetic acid, methyl

cellosolve, ethyl cellosolve, ethylene glycol, propylene glycol, dioxane, benzene, toluene, xylene, chloroform, dichloromethane, dichloroethane, tetrahydrofuran and solvents of their mixtures, with water, methanol, ethanol, propanol, isopropanol, acetic acid, methyl cellosolve, ethyl cellosolve, ethylene glycol, dioxane, toluene, chloroform, dichloromethane, dichloroethane, tetrahydrofuran and solvents of their mixtures being more preferred.

[0046]

The anode is to supply holes, for example, to the hole injecting compound, the hole transporting compound, the hole injecting and transporting compound, and the host compound. As the materials for the anode, metals, alloys, metal oxides, electrically conductive compounds, and mixtures of these materials can be used, and preferred materials are those having a work function of 4 eV or more. Specific examples of the materials for the anode include electrically conductive metal oxides, e.g., tin oxide, zinc oxide, indium oxide, and tin-doped indium oxide (ITO), or metals, e.g., gold, silver, chromium, nickel, and mixtures of these metals with the electrically conductive metal oxides, or inorganic electrically conductive substances (laminates, copper iodide, copper sulfide, etc.), organic electrically conductive materials, (polyaniline, polythiophene, polypyrrole, etc.), and laminates of these materials with ITO. Of these materials, preferred are electrically conductive metal oxides, and organic electrically conductive materials or laminates thereof, and more preferred are ITO or ITO/PEDOT-PSS laminates taking advantage of good productivity, high conductivity, transparency and the like. The layer thickness of the anode can be arbitrarily selected depending on the materials, but generally it is preferably in the range from 10 nm to 5  $\mu\text{m}$ , more preferably from 50 nm to 1  $\mu\text{m}$ , and furthermore preferably from 100 nm to 500 nm.

[0047]

The anode is ordinary formed as a layer on a substrate made such as of soda lime glass, non-alkali glass or transparent resin. In the case of using glass, it is preferred to use non-alkali glass for the material in order to reduce eluted ions. In the case of using soda lime glass, it is preferred to use one having barrier coating such as of silica thereon. The thickness of the substrate is not particularly restricted so long as it is sufficient to keep

mechanical strength, but in the case of using glass, the thickness is usually 0.2 mm or more, preferably, 0.7 mm or more. Various methods are used for the formation of the anode depending on the materials, and for example, in the case where the material is ITO, the anode is formed as a layer by, for example, an electron beam method, sputtering method, resistance heating vapor deposition method, chemical reaction method (sol-gel method, etc.), and coating of ITO dispersions. It is possible to lower the driving voltage of the device by subjecting the anode to washing or other treatments to enhance light emitting efficiency. In the case of ITO, for example, UV-ozone treatment, plasma treatment and the like are effective.

[0048]

The cathode is to supply electrons to the electron injecting compound, the electron transporting compound, the electron injecting and transporting compound, the host compound and the like. The material for the cathode is selected while considering adhesion with these compounds and the matrix compound, ionization potential, stability and the like. The material for the cathode includes metals, alloys, metal halides, metal oxides, electrically conductive compounds, organic metal salts or their mixtures or laminates. Specific examples thereof include alkali metals (e.g., Li, Na and K) and fluorides thereof, alkaline earth metals (e.g., Mg and Ca) and fluorides thereof, gold, silver, lead, aluminum, sodium/potassium alloys or mixed metals thereof, lithium/aluminum alloys or mixed metals thereof, magnesium/silver alloys or mixed metals thereof, rare earth metals such as indium and ytterbium, and salts of organic compounds with alkali metals or alkaline earth metals. Preferred materials are those having a work function of 4 eV or less, and more preferred materials are aluminum, lithium/aluminum alloys or mixed metals thereof, magnesium/silver alloys or mixed metals thereof, organic lithium salts and the like.

[0049]

The cathode may have not only a single layer structure made of the compound and the mixture described above, but also a laminate structure comprising the compound and the mixture described above. The layer thickness of the cathode can be arbitrary selected depending on the materials, but usually, it is preferably within the range from 10 nm to 5 $\mu$ m,

more preferably, from 50 nm to 1  $\mu\text{m}$ , and furthermore preferably, from 100 nm to 1  $\mu\text{m}$ . For the formation of the cathode, an electron beam method, sputtering method, resistance heating vapor deposition method, and coating method, for example, are used. It is possible to carry out vapor deposition using a single metal, or two or more components may be vapor deposited concurrently. In addition, it is possible to form an alloy electrode by vapor deposition of a plurality of metals concurrently or by vapor deposition of an alloy prepared in advance. The sheet resistance of the anode and the cathode is preferably low, and it is preferably 15  $\Omega/\square$  or less.

[0050]

Any of light-emitting compounds may be used so long as they have a function of permitting injection of holes from the anode, the hole injecting layer, or the hole transporting layer, as well as permitting injection of electrons from the cathode, the electron injecting layer or the electron transporting layer, a function of transferring injected charges, and a function of enabling light emission by offering a site for recombination of the holes and the electrons when electric field is applied, and may be those emitting light from singlet excitons and triplet excitons. Preferable light-emitting compounds include conjugated unsaturated compounds, ortho-metallated metal complexes and porphyrin metal complexes, and other light-emitting materials may be used in combination. As the light-emitting materials, polymers and low molecular materials may be used. Specifically, the compounds to be described below may be used.

[0051]

(a) Benzoxazole, benzoimidazole, benzothiazole, styrylbenzene, polyphenyl, diphenyl butadiene, tetraphenyl butadiene, naphthalimide, coumarin, perylene, perynone, oxadiazole, aldazine, cyclopentadiene, bisstyryl anthracene, quinacrydone, pyrrolopyridine, thiadiazolo pyridine, cyclopentadiene, styrylamine, aromatic dimethylidyne compounds, pyrene, derivatives thereof, etc.

(b) metal complexes of 8-quinolinol and derivatives thereof, and various metal complexes represented by rare earth complexes, etc.

(c) polythiophene, polyphenylene, polyfluorene, polyphenylene vinylene and substituted polymer compounds thereof, etc., and  
(d) ortho-metallated metal complexes or porphyrin metal

complexes, etc.

[0052]

Among the compounds described above, preferably used compounds are described below; styryl benzene, polyphenyl, diphenylbutadiene, tetraphenylbutadiene, coumarin, perylene, oxadiazole, bis-styryl anthracene, quinacrydone, cyclopentadiene, styrylamine, aromatic dimethylidyne compounds, pyrene, derivatives thereof, etc.; metal complexes of 8-quinolinol and derivatives thereof, and various metal complexes represented by rare earth complexes, etc.; polythiophene, polyphenylene, polyfluorene, polyphenylene vinylene and substituted polymer compounds thereof, etc.; and ortho-metallated metal complexes or porphyrin metal complexes, etc.

[0053]

More preferably used compounds among them are described below; styryl benzene, polyphenyl, diphenylbutadiene, tetraphenylbutadiene, coumarin, perylene, oxadiazole, bis-styryl anthracene, styryl amine, aromatic dimethylidyne compounds, pyrene, derivatives thereof, etc.; and metal complexes of 8-quinolinol, derivatives thereof, and various metal complexes represented by rare earth complexes, etc.; polythiophene, polyphenylene, polyfluorene, polyphenylene vinylene and substituted polymer compounds thereof, etc.; ortho-metallated metal complexes or porphyrin metal complexes, etc.

[0054]

As the light-emitting compound used in the present invention, at least one of ortho-metallated metal complexes and porphyrin metal complexes which are phosphorescent compounds is preferably used, and ortho-metallated metal complexes are used more preferably.

[0055]

The ortho-metallated metal complexes used in the present invention will be described. The ortho-metallated metal complexes collectively mean a compound group described, for example, in "Yuki Kinzoku Kagaku, Kiso To Oyo", written by Akio Yamamoto and published by Shokabo Co. in 1982, p. 150 and p. 232; and "Photochemistry and Photophysics of Coordination Compounds" written by H. Yersin and published by Springer-Verlag Co. in 1987, pp. 71 to 77 and pp. 135 to 146. As the central metal of the metal complex, any of transition metals may be used, however, rhodium, platinum, gold, iridium,

ruthenium, and palladium, for example, among them may be used preferably in the invention. A more preferably used metal among them is iridium. Detailed description and examples of compounds of the ortho-metatalated metal complexes are described in paragraph numbers "0152" to "0180" in JP-A-2000-254171.

[0056]

While the valence of the metal of the ortho-metatalated metal complex has no particular restriction, a valence 3 is preferred when iridium is used. The ligands of the ortho-metatalated metal complex have no particular restriction so long as they can form an ortho-metatalated metal complex. Examples of the ligand include aryl-substituted nitrogen-containing aromatic hetero-ring derivatives (an aryl group is substituted at a position on the carbon atom adjacent to the nitrogen atom of the nitrogen-containing aromatic hetero-ring, and the aryl group includes, for example, a phenyl group, a naphthyl group, an anthracenyl group, and a pyrenyl group, and the nitrogen-containing aromatic hetero-ring includes, for example, pyridine, pyrimidine, pyrazine, pyridazine, quinoline, isoquinoline, quinoxaline, phthalazine, quinazoline, naphthyridine, cinnoline, perimidine, phenanthroline, pyrrole, imidazole, pyrazole, oxazole, oxadiazole, triazole, thiadiazole, benzimidazole, benzoxazole, benzothiazole and phenanthridine); a heteroaryl-substituted nitrogen-containing hetero-ring derivative (a hetero-aryl group is substituted at a position on the carbon atom adjacent to the nitrogen atom of the nitrogen-containing aromatic hetero-ring, and the hetero-aryl group includes, for example, groups containing the nitrogen-containing aromatic hetero-ring derivatives described above, a thiophenyl group and a furyl group), 7,8-benzoquinoline derivatives, phosphinoaryl derivatives, phosphinoheteroaryl derivatives, phosphinoxyaryl derivatives, phosphinoxy heteroaryl derivatives, aminomethyl aryl derivatives, and aminomethyl heteroaryl derivatives. Among them, aryl-substituted nitrogen-containing aromatic hetero-ring derivatives, heteroaryl-substituted nitrogen-containing aromatic hetero-ring derivatives, 7,8-benzoquinoline derivatives are preferred, and phenyl pyridine derivatives, thiophenyl pyridine derivatives, 7,8-benzoquinoline derivatives are more preferred, with thiophenyl pyridine derivatives, and 7,8-benzoquinoline derivatives being furthermore preferred.

[0057]

The porphyrin metal complex to be used in the present invention is preferably a platinum complex, and more preferably, a bivalent platinum complex.

[0058]

The thickness of the organic compound layer has no particular restriction, however, the layer has a thickness preferably within a range from 1 nm to 5  $\mu\text{m}$ , more preferably, from 5 nm to 1  $\mu\text{m}$ , and furthermore preferably, from 10 nm to 500 nm.

[0059]

The manufacturing method for the organic compound layer includes, with no particular restriction, resistive evaporation, electron beam deposition, sputtering, molecular accumulation method, coating method, (e.g., spin coating method, cast coating method and dip coating method), ink jet method, printing method, and LB (Langmuir-Blodgett) method, and preferred methods are resistive evaporation, coating method, ink jet method, and printing method. In the case of coating method, ink jet method, and printing method, the organic compound may be dissolved or dispersed together with a resin component, in which the resin component includes, for example, polyvinyl chloride, polycarbonate, polystyrene, polymethyl methacrylate, polybutyl methacrylate, polyester, polysulfone, polyphenylene oxide, polybutadiene, poly(N-vinylcarbazole), hydrocarbon resin, ketone resin, phenoxy resin, polyamide, ethyl cellulose, vinyl acetate, ABS resin, polyurethane, melamine resin, unsaturated polyester resin, alkyd resin, epoxy resin and silicone resin.

[0060]

The hole injecting and hole transporting compound may be any of those compounds having any one of following functions: a function of injecting holes from the anode, a function of transporting holes, and a function of blocking electrons injected from the cathode, and either polymers or low molecular compounds may be used. Specific examples of the compound include carbazole, triazole, oxazole, oxadiazole, imidazole, polyarylalkane, pyrazoline, pyrazolone, phenylenediamine, arylamine, amino-substituted chalcone, styrylanthracene, fluorenone, hydrazone, stilbene, silazane, and their derivatives, aromatic tertiary amine compounds, styrylamine compounds, aromatic dimethylidyne-based compounds, porphyrin-based compounds, polysilane-based compounds,

poly(N-vinylcarbazole) derivatives, aniline-based copolymers, thiophene compounds, conductive high molecular oligomers such as polythiophene, substituted and unsubstituted polythiophene/polystyrene sulfonic acid mixtures, and mixtures of the compounds described above may also be used. In particular, carbazole, triazole, oxazole, oxadiazole, imidazole, phenylenediamine, arylamine, fluorenone, stilbene, silazane and derivatives thereof, aromatic tertiary amine compounds, styrylamine compounds, aromatic dimethylidyne-based compounds, aniline-based copolymers, thiophene compounds, conductive high molecular oligomers such as polythiophene, substituted and unsubstituted polythiophene/polystyrene sulfonic acid mixtures, etc. are more preferred. Among them, carbazole, triazole, oxazole, oxadiazole, imidazole, phenylenediamine, arylamine, fluorenone, silazane, and their derivatives, aromatic tertiary amine compounds, thiophene compounds, and conductive high molecular oligomers such as substituted or unsubstituted polythiophene/polystyrene sulfonic acid mixtures are furthermore preferred in view of the hole transfer function, and the lowest excited triplet energy levels.

[0061]

As the materials for the electron injecting compound, the electron transporting compound, and the electron injecting and transporting compound, any of materials may be used so long as they have any one of the following functions: a function of injecting electrons from the cathode, a function of transporting electrons, and a function of blocking holes injected from the anode. Specific examples of the materials include pyridine, pyrazine, quinoline, quinoxaline, phenanthroline, triazine, thienopyrazine, benzimidazole, benzoxazole, benzotriazole, phenanthridine, triazole, oxazole, oxadiazole, fluorenone, anthraquinodimethane, anthrone, diphenylquinone, thiopyran dioxide, carbidiimide, fluorenylidene methane, distyrylpyrazine, phthalocyanine, and derivatives thereof, heterocyclic tetracarboxylic acid anhydrides such as naphthaleneperylene, metal complexes of 8-quinolinol derivatives, metal phthalocyanines, various kinds of metal complexes containing a benzoxazole or benzothiazole as a ligand. These material may be used as a mixture or a polymer. In particular, pyridine, pyrazine, quinoline, quinoxaline, phenanthroline, triazine, phenanthridine, triazole, oxazole,

oxadiazole, fluorenone, phthalocyanine, and derivatives thereof, heterocyclic tetracarboxylic acid anhydrides such as naphthaleneperylene, metal complexes of 8-quinolinol derivatives, metal phthalocyanines, and various kinds of metal complexes containing a benzoxazole or benzothiazole as a ligand, and polymers thereof are more preferred. Among them, pyridine, pyrazine, quinoline, quinoxaline, phenanthroline, triazine, triazole, oxazole, oxadiazole, fluorenone, phthalocyanine, and derivatives thereof, metal complexes of 8-quinolinol derivatives, metal phthalocyanines, and polymers thereof are furthermore preferred.

[0062]

The host compound is not particularly restricted so long as the compound can transport exciton energy to the light-emitting compound, and can be arbitrary selected depending on the purpose. Specific examples of the compound include carbazole, triazole, oxazole, oxadiazole, imidazole, polyarylalkane, pyrazoline, pyrazolone, phenylenediamine, arylamine, amino-substituted chalcone, styrylanthracene, fluorenone, hydrazone, stilbene, silazane, anthraquinodimethane, anthrone, diphenylquinone, thiopyran dioxide, carbodiimide, fluorenylidenemethane, distyrylpyrazine, phthalocyanine and their derivatives, aromatic tertiary amine compounds, styrylamine compounds, aromatic dimethylidyne-based compounds, porphyrin-based compounds, heterocyclic tetracarboxylic acid anhydrides such as naphthaleneperylene, metal complexes of 8-quinolinol derivatives, metal phthalocyanines, and various kinds of metal complexes containing benzoxazole or benzothiazole as a ligand, polysilane-based compounds, poly(N-vinylcarbazole) derivatives, aniline-based copolymers, conductive high molecular oligomers such as thiophene oligomers, and polythiophene, and polymeric compounds such as polythiophene derivatives, polyphenylene derivatives, polyphenylene vinylene derivatives, and polyfluorene derivatives. The host compound may be used singly or two or more of them may be used in combination. In particular, in view of the lowest excited triplet energy levels, carbazole, triazole, oxazole, oxadiazole, imidazole, polyarylalkane, arylamine, fluorenone, stilbene, silazane, anthraquinodimethane, diphenylquinone, carbodiimide, fluorenylidenemethane, and their derivatives, aromatic tertiary amine compounds, aromatic dimethylidyne-based compounds, aniline-based copolymers, thiophene

compounds etc. are more preferred. Among them, carbazole, triazole, oxazole, oxadiazole, imidazole, arylamine, fluorenone, stilbene, silazane, anthraquinodimethane, diphenylquinone, carbodiimide, fluorenylidenemethane, and their derivatives, aromatic dimethylidyne-based compounds, aniline-based copolymers, thiophene compounds, etc. are furthermore preferred.

[0063]

The arylamine and derivatives thereof contained in the organic compound layer of the invention usually serves as a hole injecting and a hole transporting compound and a host compound, and it has been known that high molecular weight arylamine serves also as an electron transporting compound. Specific examples of the arylamine and derivatives thereof include triarylamine and derivatives thereof, and N-phenyl carbazole and derivatives thereof. Among them, N-phenyl carbazole and derivatives thereof are more preferably used. They may be either low molecular compounds or high molecular compounds.

[0064]

As the material for the protection layer, any materials may be used so long as they have a function of preventing water, oxygen or the like, which promotes degradation of the device, from intruding into the device. Specific examples of the materials include metals such as In, Sn, Pb, Au, Cu, Ag, Al, Ti, and Ni, metal oxides such as MgO, SiO, SiO<sub>2</sub>, Al<sub>2</sub>O, GeO, NiO, CaO, BaO, Fe<sub>2</sub>O<sub>3</sub>, Y<sub>2</sub>O<sub>3</sub>, and TiO<sub>2</sub>, metal fluorides such as MgF<sub>2</sub>, LiF, AlF<sub>3</sub>, and CaF<sub>2</sub>, polyethylene, polypropylene, polymethyl methacrylate, polyimide, polyurea, polytetrafluoroethylene, polychloro trifluoroethylene, polydichloro difluoroethylene, copolymers of chloro trifluoroethylene and dichloro difluoroethylene, copolymers prepared by polymerizing a monomer mixture of tetrafluoroethylene and at least one comonomer, fluorine-containing copolymers having a cyclic structure in the main chain thereof, water absorbent substances having a water absorption of 1% or more, and moisture-proof substances having a water absorption of 0.1% or less.

[0065]

The protective layer also has no particular restriction as to the formation method, and a chemical vapor deposition method (CVD method), vacuum evaporation method, sputtering method, reactive sputtering method, molecular beam epitaxy

(MBE) method, cluster ion beam method, ion plating method, plasma polymerization method (high frequency excitation ion plating method), plasma chemical vapor deposition (CVD) method, laser CVD method, heat CVD method, gas source CVD method, inkjet method, printing method and coating method, for example, may be adopted.

[0066]

[Examples]

The present invention will be described specifically with reference to examples below, but the invention is not restricted thereto.

Example 1

On a washed ITO substrate, an anode containing a hole injecting organic conductive material was formed by spin-coating Baytron P (PEDOT-PSS solution (polyethylene dioxythiophene-polystyrene sulfonic acid-doped body)/manufactured by BAYER AG.) as a hole injecting organic electrically conductive material at 1,000 rpm for 60 seconds, and then vacuum-dried at 150°C for 2 hours (layer thickness: about 100 nm). On this anode, a solution prepared by dissolving 20 mg of a polymer of Example Compound E-1 as an electron transporting matrix, 20 mg of Example Compound M-6 as a phosphorescent host compound, 1 mg of fac-tris (2-phenylpyridine)iridium (hereinafter referred to as Ir(ppy)<sub>3</sub>) as a phosphorescent compound and 6 mg of Example Compound E-13 as an electron injecting compound respectively in 5 ml of chloroform was spin-coated (1,000 rpm, 20 seconds) (layer thickness: 150 nm). Then, a patterned mask (a mask giving a light emitting area of 5 mm × 5 mm) was placed on the organic thin layer, and magnesium/silver of 10/1 were concurrently vapor deposited to a thickness of 250 nm, followed by vapor deposition of silver to a thickness of 300 nm ( $1.0 \times 10^{-3}$  Pa to  $1.3 \times 3 \times 10^{-3}$  Pa) in a vapor deposition apparatus. The lowest excited triplet energy levels were determined from the rising wavelengths based on phosphorescence measurement. The ionization potentials were measured by ultraviolet photoelectron spectrometer AC-1 (Riken Keiki Co., Ltd.). The results are summarized in Table 1 for each compound. The electron mobility was measured according to descriptions of Synthetic Metals, 111-112, p 331 (2000) based on TOF method at room temperature. The emission characteristics were measured as follows. DC voltage was applied to the light emitting device using ITO as an anode and magnesium/silver as

a cathode and by using Source Measure Unit 2400 model manufactured by Toyo Technica, making each device emit light to measure the luminance by using a luminance meter BM-8 manufactured by Topcon Co. and the light emission wavelength was measured using a Spectrum Analyzer PMA-11 manufactured by Hamamatsu Photonics. Further, in order to evaluate storage durability of the device at a high temperature, the device prepared was allowed to stand under the conditions of 60°C and 20% RH for 3 hours, and then, allowed to emit light. A relative luminance (a value representing a luminance after aging by a relative value, taking a luminance just after the preparation of the device as 100 at driving voltage: 10 V) was measured. The results of measurement were as follows. The electron mobility of the organic compound layer was  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more at an electric field intensity within a range from 400 to 1000 ( $(\text{V}/\text{cm})^{1/2}$ ), and the lowest driving voltage (the lowest voltage at which light emission is observed) was 8V, showing current density of 156 mA/cm<sup>2</sup> at 19V, and emitting green light at a luminance of 18030 cd/m<sup>2</sup>. The maximum light emission wavelength  $\lambda_{\text{max}}$  was 515 nm, and the maximum external quantum efficiency was 6.2%. The relative luminance after aging was 85.

[0067]

[Table 1]

	Example Compound	Lowest excited triplet energy levels (k cal/mol)	Ionization potential (eV)
Example 1	E-1	72	6.0
	E-13	63	6.0
	M-6	66	5.9
Example 2	E-3	63	6.0
Example 3	E-8	61	6.8
Example 4	E-11	62	6.7
	M-6	66	5.9
Example 5	H-2	60	5.5
	E-18	66	6.3

[0068]

Example 2

A device was manufactured in the same manner as in Example 1 except for changing the polymer of Example Compound

E-1 as an electron transporting matrix in Example 1 to a polymer of Example Compound E-3 having a similar function. In the same manner as in Example 1, the lowest excited triplet energy level and the ionization potential of the compound were measured (refer to Table 1). The electron mobility and the light characteristics were measured in the same manner as in Example 1. As a result, the electron mobility of the organic compound layer was  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  at the electric field intensity within the range described above, the lowest driving voltage was 7V, showing current density of 148 mA/cm<sup>2</sup> at a driving voltage of 16V and emitting green light with a luminance of 12910 cd/m<sup>2</sup>. The maximum light emission wavelength  $\lambda_{\text{max}}$  was 513 nm, and the maximum external quantum efficiency was 3.8%. The relative luminance after aging was 82.

[0069]

#### Example 3

A device was manufactured in the same manner as in Example 1 except for changing the polymer of Example Compound E-1 as an electron transporting matrix in Example 1 to a polymer of Example Compound E-8 having a similar function. Likewise Example 1, the lowest excited triplet energy level and the ionization potential of the compound were measured (refer to Table 1). The electron mobility and the light characteristics were measured in the same manner as in Example 1. As a result, the electron mobility of the organic compound layer was  $5 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  at an electric field intensity within the range described above, the lowest driving voltage was 5V, showing current density of 16 mA/cm<sup>2</sup> at a driving voltage of 12V and emitting green light with a luminance of 2410 cd/m<sup>2</sup>. The maximum light emission wavelength  $\lambda_{\text{max}}$  was 513 nm, and the maximum external quantum efficiency was 4.4%. The relative luminance after aging was 87.

[0070]

#### Example 4

A glass substrate (25 mm × 25 mm × 0.7 mm) on which ITO was deposited to a thickness of 150 nm (manufactured by Sanyo Vacuum Industries Co., Ltd., Tokyo) was used as a transparent support substrate. After the transparent support substrate was etched and washed, about 10 nm of copper phthalocyanine as a hole injecting organic conductive material was vapor-deposited thereon, to form an anode containing a hole

injecting organic conductive material. Then, Example Compound E-11, as an electron injecting compound, Example Compound M-6 as a phosphorescent host compound, fac-tris (2-phenylpyridine)iridium (hereinafter referred to as Ir(ppy)<sub>3</sub>) as a phosphorescent compound, and Example Compound E-13 as an electron injecting compound were vapor deposited concurrently at a mass ratio of 44:44:6:6 in a vacuum of 10<sup>-3</sup> to 10<sup>-4</sup> Pa at a substrate temperature of room temperature (layer thickness: about 100 nm). Then, a patterned mask (a mask giving a light emitting area of 5 mm × 4 mm) was placed on the organic thin layer, and magnesium/silver of 10/1 were concurrently vapor deposited to a thickness of 250 nm, followed by vapor deposition of silver to a thickness of 300 nm in a vapor deposition apparatus. Thus, a light emitting device was prepared. In the same manner as in Example 1, the lowest excited triplet energy levels and the ionization potentials of the compounds were measured (refer to Table 1). The electron mobility and the light characteristics were measured in the same manner as in Example 1. As a result, the electron mobility of the organic compound layer was  $5 \times 10^{-4} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more at an electric field intensity within the range described above, the lowest driving voltage was 4V, showing current density of 154 mA/cm<sup>2</sup> at a driving voltage of 17V and emitting green light with a luminance of 16910 cd/m<sup>2</sup>. The maximum light emission wavelength  $\lambda_{\text{max}}$  was 516 nm, and the maximum external quantum efficiency was 5.3 %. The relative luminance after aging was 78.

[0071]

#### Example 5

A device was manufactured in the same manner as in Example 4 except for using Example Compound E-18 instead of Example Compound E-11 of the electron injecting compound, and using Example Compound H-2 instead of Example Compound M-6 of the phosphorescent host compound in Example 4. In the same manner as in Example 1, the lowest excited triplet energy levels and the ionization potentials of the compounds were measured (refer to Table 1). The electron mobility and the light characteristics were measured in the same manner as in Example 1. As a result, the electron mobility of the organic compound layer was  $1 \times 10^{-4} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  at an electric field intensity within the range described above, the lowest driving voltage was 4V, showing current density of 150 mA/cm<sup>2</sup> at a driving voltage of 17V and emitting green light with a

luminance of 16060 cd/m<sup>2</sup>. The maximum light emission wavelength  $\lambda_{max}$  was 518 nm, and the maximum external quantum efficiency was 4.8%. The relative luminance after aging was 81.

[0072]

#### Comparative Example 1

A device was manufactured in the same manner as in Example 1 except for changing the polymer of Example Compound E-1 as an electron transporting matrix in Example 1 to a polymer of Comparative Example 1. The electron mobility and the light characteristics were measured in the same manner as in Example 1. As a result, while the electron mobility of the polymer of Example Compound 1 was  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or more at an electric field intensity within the range described above, the electron mobility of the polymer of Comparative Compound 1 was  $2 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  or less at an electric field intensity within the range described above, and therefore, the lowest driving voltage was as high as 11V which is higher than that of the device of the present invention, showing current density of 18 mA/cm<sup>2</sup> at 21V, and emitting light at a luminance of 1880 cd/m<sup>2</sup>. The maximum light emission wavelength  $\lambda_{max}$  was 513 nm, and the maximum external quantum efficiency was as low as 1.7%. The relative luminance after aging was 60.

[0073]

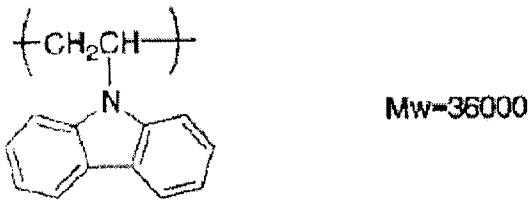
#### Comparative Example 2

A device was manufactured in the same manner as in Example 1 except for changing the polymer of Example Compound E-1 in Example 1 to a polymer of Comparative Example 2. The light emitting characteristics were measured in the same manner as in Example 1. As a result, the lowest excited triplet energy level of the Comparative Compound 2 was 58 kcal/mol which was lower than the lowest excited triplet energy level of Ir(ppy)<sub>3</sub> : 60 kcal/mol as a phosphorescent material, and therefore, energy transfer did not occur, and light emission was not observed.

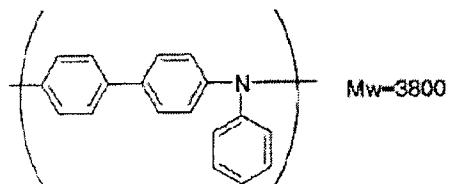
[0074]

[chemical formula 11]

#### Comparative Compound 1



Comparative Compound 2



[0075]

As a result described above, the devices prepared using the compounds of the present invention have low lowest driving voltages, showing high luminance, and high light emitting efficiency. In addition, the lowering of the luminance of the devices after being stored at a high temperature is small, and hence it can be seen that the devices are excellent in durability. Further, in the comparative examples, when the electron mobility is lower than  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  at an electric field intensity within a range from 400 to 1,000  $((\text{V}/\text{cm})^{1/2}$ , the lowest driving voltages of the light emitting devices become higher compared with those of the devices of the present invention, so the maximum external quantum efficiency is lowered more compared with that of the devices of the present invention.

[0076]

#### [Advantage of the Invention]

It has become clear that the compounds of the present invention have electron mobility of  $3 \times 10^{-5} \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$  at an electric field intensity within a range from 400 to 1,000  $((\text{V}/\text{cm})^{1/2}$  in the organic compound layer, and when the organic compound layer contains a light emitting compound, a single layer device whose lowest driving voltage is low, and which has high luminance and high light emitting efficiency can be formed. Moreover, devices showing little degradation of luminance after being stored at a high temperature and having excellent durability can be provided. The single layer device can be manufactured through an extremely simple fabrication process compared with that of laminate devices, which is advantageous from a practical viewpoint.